

MATCHING LED AND INCANDESCENT AVIATION SIGNAL BRIGHTNESS

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INTRODUCTION

Airfield lighting is increasingly using light-emitting diode (LED) sources, because of their potential for long operating life and reduced maintenance requirements [1]. However, LED signals being too bright is a complaint that has sometimes been heard from pilots [2]. Generally, colored LED signal lights have narrower spectral power distributions than incandescent signals that produce more saturated colors, which tends to result in the perception of increased brightness for the same luminance [3]. White LED signals are available in a wide range of correlated color temperatures (CCTs) and these also can be judged as brighter than white incandescent signal lights of the same intensity [4].

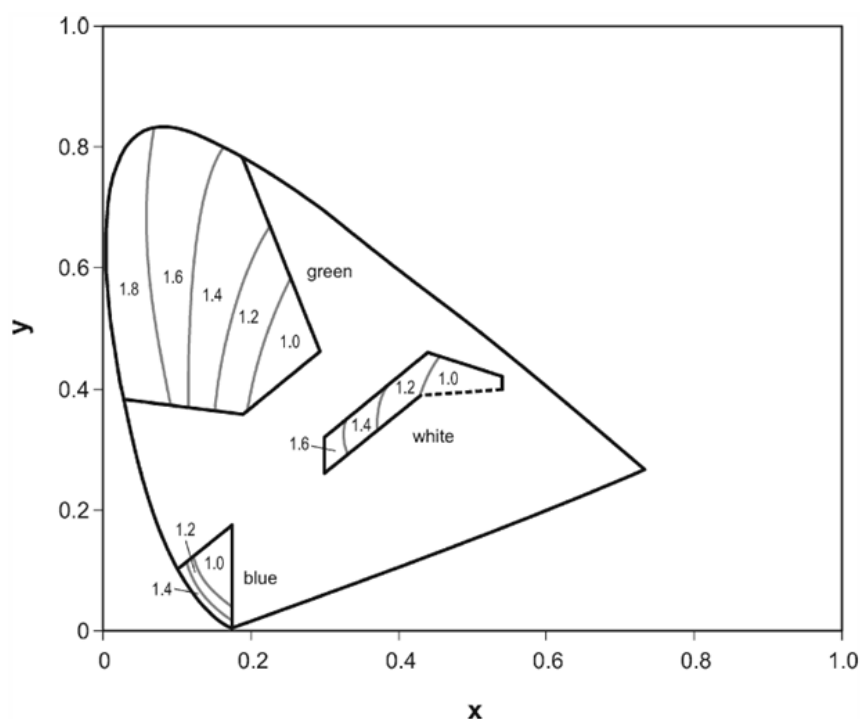


Figure 1. Contours of equivalent brightness (relative to incandescent signals) for different chromaticities within the white, green and blue color boundaries [5].

At the request of the Federal Aviation Administration (FAA), researchers at the Lighting Research Center (LRC) developed a set of “brightness correction factors” for white, green, and blue signal lights, to match the apparent brightness of LED and incandescent airfield signal lights [5]. Contours of equivalent brightness relative to incandescent signal lights are shown in Figure 1. Red and yellow LED signals also differ from their incandescent counterparts in terms of spectral power distributions. The objective of the present paper is to describe brightness-luminous intensity characteristics of the five aviation signal light colors as well as the impact of factors such as the background light level, number of light sources, and the presence of fog on perceived brightness.

COLOR-SPECIFIC DATA

White

White LEDs differ from colored LEDs in that they have more than one spectral component. White aviation signal products presently use phosphor-converted white LEDs, which are essentially blue LEDs that are surrounded by an yttrium-aluminum-garnet (YAG) phosphor layer. When the phosphor particles absorb a photon from the blue LED, it converts the energy into longer-wavelength yellow light. Some blue light is transmitted through the phosphor layer without being converted, and the resulting mixture of blue and yellow light appears white. By controlling the density and thickness of the phosphor layer as well as sometimes using a small amount of another phosphor type that converts blue to red light, a wide range of CCTs can be generated from 2700 K to 8000 K. In comparison, an incandescent source has a CCT of around 2700 K.

Bullough et al. [5] compared the brightness perception of white incandescent point source simulated aviation signals (with a CCT of 2600 K) to LED point sources having CCTs of 3300 K or 7100 K, viewed against a dark background, for a range of intensities equivalent to several candelas to thousands of candelas. The 3300 K source was, on average, approximately 1.2 times brighter than the incandescent source, and the 7100 K source was, on average, about 1.6 times brighter, for the same luminous intensity. For a 6100 K LED near the leftmost ("blue") boundary of the present chromaticity region for white LED aviation signal lights [6], there would be expected to be a brightness increase by a factor of 1.5 over the incandescent white signal at the same intensity. Bullough et al. [5] also found that the relative brightness increase of white LED signals over incandescent signals was not affected by the background luminance (either <0.01 cd/m^2 or 0.2 cd/m^2), nor by whether the light signals shown were presented in an array of three identical signals. Thus, under clear viewing conditions, the intensity of a white LED source with a CCT near 6100 K can be reduced to **67%** ($1/1.5$) of the intensity of a white incandescent source while maintaining equivalent brightness. For an LED with a CCT near 3300 K, the intensity could be reduced to **83%** ($1/1.2$) of the incandescent intensity to maintain equivalent brightness.

Blue

Bullough et al. [5] compared the brightness of simulated blue-filtered incandescent signal lights with blue LED lights using LEDs with peak wavelengths of 450 and 470 nm, for a wide range of intensities. Both LEDs were judged to be just over 40% brighter than the incandescent source at the same intensity. As with the white LED signals, the relative brightness differences between incandescent and LED signals did not change as a function of background luminance, nor as a function of the number of signals viewed at a time. In order to maintain equivalent brightness, the luminous intensity of a blue LED source with either peak wavelength could be reduced to **72%** ($1/1.4$) of the incandescent intensity.

Green

Bullough et al. [5] also compared green incandescent signals to several different green LEDs with chromaticities throughout the permissible chromaticity region for green aviation signals, for a range of intensities. A green LED with a peak wavelength of 525 nm was judged 1.4 times brighter than an incandescent signal of the same chromaticity, and a green LED with a peak wavelength of 505 nm was judged 1.65 times brighter. This is similar in magnitude to the difference in brightness for a pair of green LED (with a peak wavelength near 505 nm) simulated traffic signals viewed in daytime conditions compared to a pair of incandescent green traffic signals [6] of the same intensity. Bullough et al. [5] also found no effect of background light level or the number of lights on the relative brightness of LED signals. Therefore, a green LED with a peak wavelength of 525 nm should be reduced to **72%** ($1/1.4$) of the intensity of a green incandescent signal to achieve equivalent brightness. For a green LED with a peak wavelength of 505 nm, the intensity could be reduced to **61%** ($1/1.65$) of the incandescent intensity.

Yellow and Red

Chromaticities of yellow incandescent and LED signals and of red incandescent and LED signals meeting aviation signal lighting requirements are quite similar. Because of this, there is little expected difference in the perception of brightness between yellow LED and incandescent signal lights, nor between red LED and incandescent signals. This was confirmed by Bullough et al. [6] who found, for simulated traffic signals viewed under daytime conditions, that yellow LED signals were judged as similarly bright to yellow incandescent signals of the same intensity. The same was true for red LED and incandescent signals. For this reason, LED intensity for yellow and red signals should not be adjusted to achieve the same apparent brightness as yellow and red incandescent signals of the same intensity.

VIEWING IN FOG

As mentioned previously, all of the results described above correspond to viewing conditions in clear atmospheric conditions. When fog is present, light from multiple light sources is scattered and some of the light from a given source will be superimposed over the image of another source in the field of view. Bullough et al. [5] measured the relative brightness of simulated blue, white and green signal lights using incandescent and LED sources when viewed through a simulated fog that reduced the intensity of a light by a little more than half and scattered the light. For the white signals, the brightness enhancement for the LED was reduced by about 30% in fog, so that a 6100 K CCT LED would need to be reduced to **74%** of the intensity of an incandescent signal to be judged equally bright, and a 3300 K CCT LED would need to be reduced to **88%** of the incandescent intensity.

For blue and green signals the relative reduction of LED brightness in fog was about half, as measured by Bullough et al. [5]. This means that blue LED signals would need to be reduced to **86%** of the intensity of an incandescent blue signal to achieve equivalent brightness. A green LED signal with a peak wavelength of 525 nm would also need to be reduced to **86%** of the intensity of an incandescent signal of the same nominal color, and a green LED signal with a

peak wavelength of 505 nm would need to be reduced to **81%** of the incandescent intensity to appear equally bright in fog.

Caveat

The measurements by Bullough et al. [5] in simulated fog represented a single specific condition, using simulated fog that approximated fog with a nighttime visibility of 1 km as viewed through a distance of 0.25 km. In addition, there were no other light sources other than the LED and incandescent sources providing scattered light within the scenes viewed by observers. Therefore the effects of fog in a range of real-world conditions experienced by pilots could differ substantially from the effects summarized in the present paper. Airports wishing to adjust the luminous intensities of LED signal lights to achieve equivalent brightness as incandescent signals may wish to forgo adjustments when fog is present.

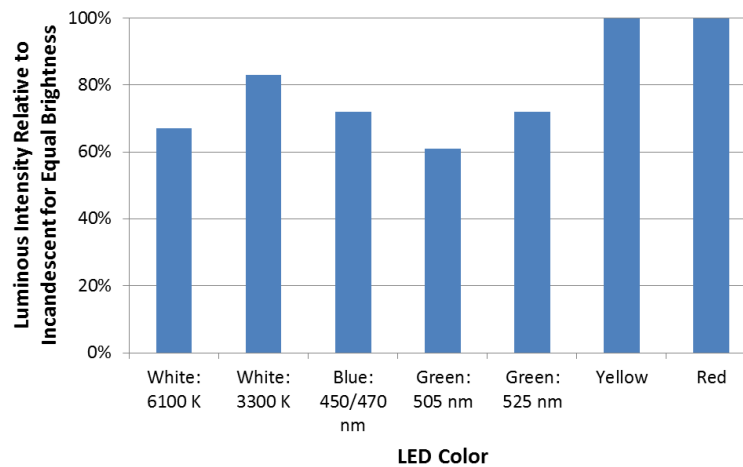


Figure 2. Relative luminous intensity needed by LED signals of various colors to match incandescent signal brightness.

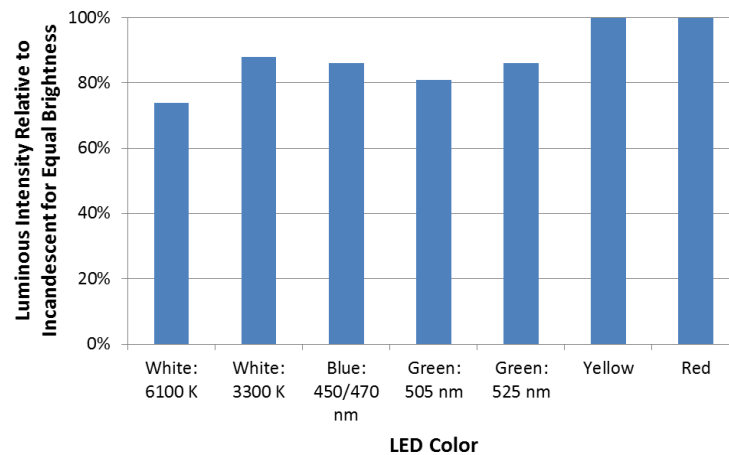


Figure 3. Relative luminous intensity needed by LED signals of various colors to match incandescent signal brightness under the fog conditions used by Bullough et al. [5].

SUMMARY

Figure 2 shows the relative luminous intensity needed for various LED aviation signal light colors to produce equivalent apparent brightness as their incandescent counterparts. As described above, these intensities never exceed 100%, suggesting that LED sources tend to appear as bright (for yellow and red) or brighter (for white, blue and green) than incandescent signals of the same nominal color. Since Figure 2 represents apparent brightness in clear viewing conditions, Figure 3 shows the corresponding luminous intensity values for the simulated fog conditions used by Bullough et al. [5] in their study. To the extent fog conditions in the real world will differ from those used to generate the values in Figure 3, differences from 100% may be larger or smaller than shown in this figure. Operational control that equalizes luminous intensity of LED and incandescent signal lights in fog may be desirable to avoid situations in which the brightness of LED signals appears lower than incandescent.

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